NASA TT F-10,967

NASA TT F-10,967

DETERMINATION OF THE MASSES AND DENSITIES OF METEORIC BODIES BY PHOTOGRAPHIC OBSERVATIONS

Ye. V. Sandakova, A. A. Demenko and V. V. Benyukh

Translation of "Opredeleniye mass i plotnostey meteornykh tel po fotograficheskim nablyudeniyam 1958-1959 gg."
Informatsionnyy Byulleten' "Materialy Mezhdunarodnogo Geofizicheskogo Goda"
No. 6, pp. 20-24, 1964

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 MAY 1967

DETERMINATION OF THE MASSES AND DENSITIES OF METEORIC BODIES BY PHOTOGRAPHIC OBSERVATIONS

Ye. V. Sandakova, A. A. Demenko and V. V. Benyukh[1]

ABSTRACT. Results are presented on the determination of masses and densities of meteoric particles by photographic observations at the Kiev Astronomical Observatory in 1958-1959. Values are obtained for various sections of the path of the meteoric particles. The observed change in the density of the meteor body with altitude is explained by fragmentation during flight.

The physical theory of meteors permits determination of the mass of meteoric particles by photographic observations by various methods. /20*

While the body moves in the atmosphere with a velocity exceeding several kilometers per second, the force of resistance is the basic force acting on it. The equation of deceleration in this case can be written

$$M \frac{dv}{dt} = -\Gamma S \rho v^2, \tag{1}$$

where M is the mass of the meteoric body, v is its velocity, ρ is the density of the atmosphere at that section of the path where the mass is determined; Γ is the coefficient of resistance of the medium; S is the area of the "midsection" of the cross-section.

If $\frac{S}{M}$ can be expressed in terms of the density of the meteoric body δ and if we introduce the dimensionless coefficient A_0 characterizing its form, the mass can then be determined by the formula

$$M = \frac{A_0^3 \Gamma^3 \rho^3 v^6}{\delta^2 w^3}, \tag{2}$$

where w is the deceleration of the meteoric particle. The mass, obtained according to (2), is usually called the dynamic mass. Several quantities which cannot immediately be determined from observations enter the formula presented. However, it is possible to evaluate their effect on the value of the mass. The coefficient ΓA_0 varies as a function of the shape of the body. For a sphere, ΓA_0=1.21 can be taken; investigations conducted with bodies of an irregular and clastic form in the range of astroballistic velocities give a value of ΓA_0=0.71 (ref. 1).

* Numbers in the margin indicate original pagination in the foreign text.

[1] Kiev State University

ΓA_0 may be considered included within the limits 1.21-1.71. An inaccurate value for ΓA_0 consequently yields no natural error in determining the masses. In our operations, $\Gamma^3 A_0^3=0.422$ (ref. 2) was used.

The atmospheric density at the path of motion of the meteoric body can be determined from published rocket data. Data relating to the standard atmosphere ABCD-1959 (ref. 3) were used in this work. The density was undertaken for altitudes corresponding to the points chosen for the meteor. /21

A noticeable effect on the determination of the mass may be shown by the value of the density of the meteoric body. In relation to this there exist various suppositions (refs. 4, 5). The dynamic masses were calculated for the following presumed densities: $\delta=3g/cm^3$; $0.5g/cm^3$; $0.1g/cm^3$.

The remaining quantities entering formula (2) can be established from observations for each meteor.

The mass of the meteoric body can be determined through photometric treatment of the meteor photographs.

The equation of luminosity is known to have the form

$$I = \tau_0 \cdot \frac{U^3}{2}\left[-\frac{dM}{dt}\right], \quad (3)$$

where I is understood to mean the illuminating power of the meteor.

The mass of the meteoric body can be determined by formula

$$M = \frac{2}{\tau_0}\int_{t_1}^{t_2}\frac{I}{v^3}\,dt. \quad (4)$$

The mass, determined according to formula (4), is called the photometric mass. Inaccuracy in determination of the mass can be introduced here only by the coefficient of luminosity. The value $\tau_0=10^{-9.07}$ was given by E. Öpik for meteoric particles with a density of $\delta=3.5g/cm^3$. In 1955, on the basis of new theoretical and experimental data, Öpik gave a new value of $\tau_0=10^{-9.30}$ for $\delta=0.5g/cm^3$.

We determined the masses for both values of τ_0. For $\tau_0=10^{-9.07}$ log $I=9.84-0.4m_{100}$, for $\tau_0=10^{-9.30}$ log $I=9.72-0.4m_{100}$, where m_{100} is the absolute stellar quantity of the meteor. As the table shows, the difference in τ_0 almost double the values of the mass.

The method of determination of stellar quantities used at the Kiev Astronomical Observatory was described earlier (ref. 6).

Using the equations

$$M\frac{dv}{dt} = -\Gamma S \varrho v^2,$$

vaporization

$$\frac{dM}{dt} = -\Lambda S \varrho \frac{v^3}{2Q}, \tag{5}$$

luminescence

$$I = -\frac{1}{2}\tau_0 v^3 \frac{dM}{dt},$$

the mass of the meteoric body can be determined by the formula

$$M = \frac{2I}{\tau \sigma v^3 w}. \tag{6}$$

The method of determining the mass with the aid of formula (6) is called the ballistic method.

Besides the quantities already known, σ--the coefficient denoting the rate of vaporization--enters. Photographic observations permit determination of σ for individual intervals in the meteor path by the formula

$$\sigma = I\left(\int_{t_1}^{t_2} I dt\right)^{-1}\left(v\frac{dv}{dt}\right)^{-1}. \tag{7}$$

We carried out such determinations for those intervals of the path for which the mass was determined (see table). However, we could not use them in determining the masses by the ballistic method because then we would have obtained absolutely the same values as by the photometric method. This is clear if σ determined according to (7) is substituted into (6). Consequently, in computing the masses by the ballistic method it is necessary to decide the quantity σ not from the formula (7) presented above. /23

H km	km/sec	km/sec^2	Photometric Mass (g)		Ballistic mass (g)	Dynamic Mass			Density of Meteoric Particle of (g/cm^3)	σ
			log τ_0= -9.07	log τ_0= -9.30		δ=3 g/cm^3	δ=0.5 g/cm^3	δ=0.1 g/cm^3		
					Meteor					
97,4	59,7	2,5	0,96	0,94	4,22	$3,32\cdot10^{-5}$	$1,20\cdot10^{-3}$	0,03	0,017	$2,4\cdot10^{-12}$
94,5	59,2	9,9	0,47	0,79	1,53	$0,29\cdot10^{-5}$	$0,10\cdot10^{-3}$	$0,03\cdot10^{-1}$	0,006	$1,0\cdot10^{-12}$
92,6	58,6	16,6	0,36	0,61	0,94	$0,20\cdot10^{-5}$	$0,07\cdot10^{-3}$	$0,02\cdot10^{-1}$	0,005	$0,8\cdot10^{-12}$
					Meteor					
97,2	60,8	1,2	0,16	0,27	6,28	$3,78\cdot10^{-4}$	$1,40\cdot10^{-2}$	0,34	0,113	$12,8\cdot10^{-12}$
96,7	60,8	1,8	0,14	0,22	4,34	$1,54\cdot10^{-4}$	$0,55\cdot10^{-2}$	0,14	0,079	$10,4\cdot10^{-12}$
95,9	60,7	3,0	0,11	0,19	0,70	$0,50\cdot10^{-4}$	$0,18\cdot10^{-2}$	0,04	0,048	$2,0\cdot10^{-12}$
93,3	60,3	18,0	0,03	0,05	0,31	$0,01\cdot10^{-4}$	$0,04\cdot10^{-3}$	$0,01\cdot10^{-1}$	0,014	$3,3\cdot10^{-12}$
					Meteor					
99,3	60,4	3,2	0,24	0,42	4,77	$6,39\cdot10^{-6}$	$2,02\cdot10^{-4}$	$0,50\cdot10^{-2}$	0,011	$6,2\cdot10^{-12}$
98,9	60,3	7,9	0,24	0,41	1,94	$0,47\cdot10^{-6}$	$0,17\cdot10^{-4}$	$0,04\cdot10^{-2}$	0,003	$2,4\cdot10^{-12}$
98,6	60,2	11,0	0,22	0,37	1,34	$0,19\cdot10^{-6}$	$0,07\cdot10^{-4}$	$0,02\cdot10^{-2}$	0,002	$1,9\cdot10^{-12}$
98,3	60,1	16,8	0,21	0,35	0,88	$0,06\cdot10^{-6}$	$0,02\cdot10^{-4}$	$0,01\cdot10^{-2}$	0,001	$1,3\cdot10^{-12}$
97,7	60,0	31,0	0,17	0,29	0,39	$0,01\cdot10^{-6}$	$0,01\cdot10^{-4}$	$0,01\cdot10^{-3}$	0,001	$0,7\cdot10^{-12}$
					Meteor					
90,8	58,0	1,5	0,03	0,04	1,51	$0,80\cdot10^{-2}$	0,29	—	1,250	$17,7\cdot10^{-12}$
90,4	58,0	3,2	0,03	0,04	0,89	$0,09\cdot10^{-2}$	0,03	0,83	0,436	$11,2\cdot10^{-12}$
90,1	57,9	4,5	0,02	0,04	0,59	$0,04\cdot10^{-2}$	0,01	0,37	0,300	$7,7\cdot10^{-12}$
89,7	57,8	9,0	0,02	0,04	0,24	$0,01\cdot10^{-2}$	$0,03\cdot10^{-1}$	0,06	0,132	$3,5\cdot10^{-12}$
99,4	57,5	34,0	0,02	0,03	0,05	$0,01\cdot10^{-3}$	$0,04\cdot10^{-3}$	$0,01\cdot10^{-1}$	0,002	$0,8\cdot10^{-12}$
					Meteor					
94,4	70,6	37,0	0,08	0,13	0,11	$1,67\cdot10^{-7}$	$0,60\cdot10^{-5}$	$1,50\cdot10^{-4}$	0,003	$0,5\cdot10^{-12}$
94,0	70,2	57,0	0,07	0,12	0,07	$0,54\cdot10^{-7}$	$0,20\cdot10^{-5}$	$0,49\cdot10^{-4}$	0,002	$0,3\cdot10^{-12}$
93,6	69,5	81,0	0,06	0,11	0,06	$0,25\cdot10^{-7}$	$0,89\cdot10^{-6}$	$0,22\cdot10^{-4}$	0,001	$0,3\cdot10^{-12}$
92,8	68,0	131,0	0,05	0,09	0,04	$0,86\cdot10^{-8}$	$0,31\cdot10^{-6}$	$0,08\cdot10^{-4}$	0,001	$0,2\cdot10^{-12}$

According to our determinations, individual values of σ are contained within the limits from $0.2 \cdot 10^{-12}$ to $17 \cdot 10^{-12}$, i.e., increase 85 times. The ballistic masses presented in the given article were calculated with a mean value of $\sigma = 4 \cdot 10^{-12}$.

The masses determined by the dynamic and photometric methods differ by several orders. This difference can be related either to inaccuracy in the values of the density of the meteoric particle or to inaccuracy in the deceleration quantity. To clarify the effect of the density of the meteoric particle on the determination of the mass by the dynamic method, the masses were computed for various density values. The convergence of the values obtained for the mass was better with lower densities for the meteoric particles. The convergence of the masses is obtained for extremely low densities: for the meteor No. 42 (7) for $\delta = 0.002 g/cm^3$, and for the meteor No. 29 (15) for $\delta = 0.4 g/cm^3$.

In comparing the masses, deceleration plays a vital role since it enters formula (2) in the third power. The lower limit of accuracy in determination of deceleration, according to our observations, is 30 percent; however, even a variation of 100 percent in the deceleration value does not explain the observed divergences in the masses. The dynamic masses for deceleration w and 2w were calculated for three meteors.

Meteor No. 17

	w, км/sec	2w, км/sec
	2,5	5,0
M, г	0,03	$0.09 \cdot 10^{-1}$

Meteor No. 24

	w, км/sec	2w, км/sec
	11.0	22.0
M, г	$0.02 \cdot 10^{-2}$	$0.02 \cdot 10^{-3}$

Meteor No. 40 (5)

	w, км/sec	2w, км/sec
	34.0	68.0
M, г	$0.01 \cdot 10^{-1}$	$0.02 \cdot 10^{-2}$

An increase in the deceleration value from 2 to 2w significantly changes the value of the masses, but does not clarify the divergence between photometric and dynamic masses.

Of all the methods considered, the photometric method is the least burdened with errors, since all the quantities entering formula (4) except τ_0 are given by observations. Therefore, considering the photometric masses the truest and substituting their values into equation (2), it is possible to determine the density of the meteoric particles. The density obtained is quite low, for it varies along the meteor path in all cases, decreasing with altitude.

The difference between the dynamic and photometric masses, the low density of the meteoric particles, and its variation with altitude--all this can be clarified if we assume that the meteors fragment. In the case of fragmentation of the meteoric body the volume luminescent fragments contain is greater than in unfragmented, and the meteor's effect proceeds as if it were related to a larger meteoric body.

In this supposition the photometric masses must be more dynamic. The values of the masses obtained by use of photometric evaluation are known to always be actually greater than values of masses found with formula (2).

In determination of the masses of meteoric particles by the means indicated and their densities, five meteors were chosen from those observed at the Kiev Astronomical Observatory stations in 1958-1959 in which the brilliance and deceleration were more reliably determined. For all meteors, mean values of decelerations and velocities were used (see table).

REFERENCES

1. Astapovich, I. S. Meteornyye yavleniya v atmosfere Zemli (Meteoric Phenomena in the Earth's Atmosphere). Izd-vo Fiziko-Matematicheskoy Literatury, 1958.
2. Kasheyev, B. L. and Lebedinets, V. N. Radiolokatsionnyye issledovaniya meteornykh yavleniy (Radar Investigations of Meteoric Phenomena). Izd-vo Akademii Nauk SSSR, 1961.
3. Kondrat'yev, K. Ya. Meteorologicheskiye issledovaniya s pomoshch'yu raket i sputnikov (Meteorological Investigations With the Aid of Rockets and Satellites). Izd-vo AN SSSR, 1962.
4. Öpik, E. J. Problems in the Physics of Meteors. American Journal of Physics, 26,70, 1958.
5. Whipple, Ye. N. On Meteor Masses and Densities. Astronomical Journal, 57, 28, 1952.
6. Sandakova, Ye. V. Fotometriya meteorov (Photometry of Meteors). Informatsionnyy Byulleten' Mezhdunarodnogo Geofizicheskogo Goda (MGG). No. 2, Izd-vo AN UkSSR, 1960.

Translated for the National Aeronautics and Space Administration
by John F. Holman Co. Inc.
WASHINGTON, D.C. 20037
NASw-1495